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CONFERENCE REPORT

Water in life cycle assessment—50th Swiss Discussion Forum on Life Cycle Assessment—Zürich, 4 December 2012

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Abstract Water use, its impacts and management, have become a focus of attention in the past decade in the context of climate change and increasing consumption (in particular of food and agricultural products) due to a growing global population. Many efforts have been made to include water-related issues in life cycle assessment (LCA) in various ways, from the long-standing eutrophication, acidification, and ecotoxicity methods, to the more recent water consumption aspects. Four years on from the first discussion forum on water in LCA (35th Swiss Discussion Forum on LCA, Zürich, 5 June 2008), numerous developments have occurred, resulting in a rich palette of approaches. Significant challenges still remain, related to the complexity of water systems and ecosystems, and certain impacts are still not considered. New challenges have emerged, such as how to fit these "pieces" together to form a coherent and comprehensive approach for assessing the impacts of water use (both degradative and consumptive). Practice has started to apply certain water consumption-related approaches and an early feedback between practitioners and developers is essential to ensure a harmonious further development. The 50th Swiss Discussion Forum on Life Cycle Assessment (DF-50) gave a brief overview of the current status of water use in LCA, and then focused on the following topics in three main sessions: (1) a selection of recent research developments in the field of impact assessment modeling; (2) identification of new and remaining challenges where future effort could be concentrated, with a focus on spatial and temporal resolution; (3) and experiences and learnings from application in practice. Furthermore, several short presentations addressed the issues of inventory requirements and comparison of impact assessment approaches. The DF-50 was concluded with a discussion workshop, focusing on four issues: which degree of regionalization is desirable, how to address data gaps in inventories, the comparability of different impact assessment approaches, and the pros and cons of including positive impacts (benefits). Numerous recent developments in life cycle impact assessment have tackled impact pathways, spatial and temporal resolutions, and uncertainties. They have lead to an increase of the completeness of impact assessment, but also of its complexity. Although developments have also occurred in inventories, the gap between impact assessment and inventory is challenging, which in turn limits the applicability of the methods. Regionalization is confirmed as an essential aspect in water footprinting; however, its implementation requires concerted effort by impact assessment developers and software developers. Therefore, even though immense progress has been made, it may be time to think of putting the pieces together in order to simplify the applicability of these tools: enabling the support of improvements in companies and policy is the ultimate goal of LCA. The recordings and presentations of the DF-50 are available for download from www.lcaforum.ch.

Keywords Application · Consumptive and degradative water use · Discussion forum · Impact assessment · Inventory gaps · Regionalization · Water footprint

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1 Introduction and status

Water use and its impacts are a key topic for a sustainable future, in the context of climate change and a growing global population (World Water Assessment Programme 2009). Life cycle assessment (LCA) is a tool which allows assessment of impacts and identification of burden shifting in environmental impact assessment, two aspects which are of high importance when assessing water use (Ridoutt and Pfister 2009). Water-related issues have been addressed in LCA in the past decade in many ways, resulting in a complex array of methods addressing different water use types and sources, pathways, categories and endpoints, and with different spatial and temporal resolutions (Kounina et al. 2012). The current interest of practice for operational and comprehensive methods addressing water use in LCA requires a discussion of the application of the existing and upcoming methods, their consistency, compatibility, comparability, and an exchange on future requirements and remaining challenges to address. The 50th Swiss Discussion Forum on LCA (DF-50) on 4 December 2012 in Zürich brought together researchers and practitioners from LCA and beyond, with the goal of presenting the latest status and developments from research for water use in LCA, identifying the main challenges to address next, and learning from recent experiences in practice. *Anne-Marie Boulay* (Ciraig, Canada) started the DF with an overview of the current status of water footprinting. This is now accepted by most to reflect impacts as well as inventories of water use. It should also take into consideration both quantitative and qualitative water use and should be regionalized. Two main initiatives are currently addressing technicalities: the WULCA working group of the UNEP-SETAC Life Cycle Initiative, and the development of the ISO Standard 14046 for water footprinting. The first seeks to evaluate and compare methods for water use impact assessment in order to provide recommendations to research and practice; several publications are already available and work is ongoing. The second was initiated in 2009, is still in progress, and the standard is expected to be available in 2014. It is expected that among others, it will recommend a life cycle-based water footprint, including impact assessment for both quantitative and qualitative aspects. Furthermore, some remaining issues were identified: which pathways should be included, whether to aggregate impacts from different pathways into a single indicator, whether some pathways overlap and cause double counting, and how well the existing methods are integrated into LCA software and are compatible with inventories.

2 Recent developments in impact assessment modeling

This session provided an overview of some of the newest developments in impact assessment modeling of water use. *Francesca Verones* (ESD, ETH Zürich, Switzerland) presented a new impact assessment method to evaluate the impacts of surface and groundwater consumption on wetlands of international importance. A fate factor (reflecting the loss of surface area of wetlands due to consumption from rivers or groundwater which feed the wetland) is combined with an effect factor (estimating the potential loss of species due to a loss of habitat area, based on the species–area relationship for different taxa). The resulting characterization factor gives the potential loss of species per consumed amount in species equivalents×year per cubic meter. This was calculated in a spatially explicit way for all watersheds across the globe which contains wetlands of international importance. A case study for rose cultivation in Kenya showed that the impacts of water consumption on wetlands could reach approximately 10 % of the total ecosystem damage, which is in the same order of magnitude as land use. A major issue identified is how to address the data gaps: in this example, data was available only for wetlands of international importance, which represent only a fraction of all wetlands; however, consumption in regions with no characterization factor cannot be considered to have no impacts on wetlands in general. Comparability with other methods relating water use to impacts on biodiversity should be investigated, and uncertainties remain, due to lack of adequate hydrogeological models for detailed resolution and global coverage. Similar issues are present in many other impact assessment methods for water use.

Ligia Azevedo (Radboud University Nijmegen, Netherlands) discussed the influence of different analysis approaches of species sensitivity distributions on the calculation of effect factors for freshwater eutrophication. The basis for the construction of SSDs, in this case, are curves of species richness as a function of total phosphorus (TP). These curves are bell-shaped, with a maximum species richness occurring at an optimal TP. This implies that an increase in TP, for background TP lower than this optimum, would actually lead to a benefit as regards species richness of the ecosystem (although it may lead to a loss of niche oligotrophic species). Such situations are not considered in LCA: this is a first unresolved issue. A second issue arises when computing the effect factor from the SSD curve, relating the potentially non-occurring fraction of species due to an increase of TP beyond the optimum. The effect factor can be calculated in several ways: a linear effect factor considers the overall average loss beyond the optimum TP, independently of the actual background TP; a marginal effect factor uses the derivative of the curve at the background TP; an average effect factor considers the average loss between the background TP and the optimum. Differences in the characterization factor due to the choice of effect factor approach were shown to reach 7 orders of magnitude. The resulting variability in the characterization factor can only be imagined, since this is without even considering variability in the fate factor. The choice of effect factor approach is influenced by the data availability of background TP, and whether a target TP is defined. This example illustrates that comparability of methods should be kept in mind when seeking to compare impacts.

In a short presentation, *Anastasia Papangelou* (ESD, ETH Zürich, Switzerland) gave a further example for eutrophication impact modeling by addressing the case of brackish waters. Indeed, these are generally treated in the same way as freshwater in LCA, and are accordingly assessed for phosphorous (P) eutrophication. However, when calculating characterization factors for non P-limited Dutch brackish lakes, for both P and nitrogen (N), impacts on ecosystem quality due to N were shown to be approximately four times higher than due to P. Hence, the question remains whether eutrophication for the case of brackish waters should be assessed for both N and P emissions. Additional issues raised were again the choice between using an average or a marginal effect factor (this choice affected the results by 1 order of magnitude), and how to extend the data-demanding and site-specific approach (conducted on Dutch lakes only) to a larger spatial coverage.

3 Challenges

This session provided insight into some of the old and new challenges related to water use in LCA and how these are being or could be tackled. *Stephan Pfister* (ESD, ETH Zürich, Switzerland) presented advances in the Water Stress Index (WSI), with insights on the importance of using up-to-date data for modeling, of considering higher temporal resolution and of distinguishing surface and groundwater consumption. The WSI consists of a global spatially explicit set of characterization factors, which weight consumption of water by the local water stress (an advanced use-to-availability ratio). When calculating the WSI per month rather than per year, the variability of the WSI can be assessed and can provide information on the maximal error incurred if using the yearly average; monthly WSI is above all relevant for agricultural water use. However, inventory data is not yet available at monthly resolution. A possible compromise is to use a weighted yearly average of the monthly WSIs, which reveals a higher stress in many watersheds compared to the original yearly WSI. Additional issues which arise when using monthly WSIs are the consideration of storage effects (dams, groundwater), and of nonconsumptive withdrawals, which nevertheless may induce temporary scarcity. Certain regions obtain a much higher WSI if considering withdrawals rather than consumption only. The distinction of groundwater and surface water WSIs also shows that some regions suffer much more from groundwater scarcity and others more from surface water scarcity. However, the overall WSI seems to capture both effects quite well. Uncertainties in the modeling chain were also presented and lie mainly in the data accuracy for estimating global water availability and use, as well as the modeling assumptions (such as the choice of distribution function and the level of spatial and temporal aggregation). A priority to reduce uncertainties is the improvement of hydrological models.

Chris Mutel (ESD, ETH Zürich, Switzerland) tackled the issue of integrating the regionalization of water use and impacts into LCA calculations. Many water use impact assessment methods use a different spatial resolution, which can furthermore differ from the spatial resolution of the inventory data. Geographical Information Systems (GIS) allow handling this complexity with variable effort. GIS-based LCA can be done in several ways and tends to be either resource intensive or require high computer skills from the user. Combining two complete models (a complete GIS model for all processes and an entire LCA model) is very powerful but very resource intensive, and is no longer really LCA but rather specific modeling for a particular case. A first compromise approach is regionalizing all the foreground processes. This implies creating an own separate foreground data set with geocoding and a GIS tool, and typically also doing the impact assessment in a separate file (for recent, spatially explicit impact assessment methods), rather than an all-in-one ready-to-use solution in an LCA software, for instance. This approach avoids having to update the entire inventory database with spatially explicit data; however, it is difficult to iterate and include variations, and can miss significant impacts in the background processes. A second approach is to regionalize only the processes which are highly sensitive to regionalization. This would reduce the effort of regionalizing data. However, most LCA softwares do not provide systematic uncertainty and sensitivity testing; therefore, addressing this would require higher computer skills. Furthermore, characterization factors are often not further aggregated than their original spatial resolution, which may conflict with a process that could otherwise remain nonregionalized. A third approach is to precalculate intersections between different impact assessment and process location layers (e.g., overlap between a characterization factor set at watershed resolution, with countries), and integrate this into LCA software. This requires effort from software developers, but almost no effort from practitioners; however the resulting set of locations to choose from is no longer flexible for the practitioner. A fourth approach is the use of novel software, which include GIS functionalities directly within the LCA tools (or vice versa). This requires only moderate resources and computer skills. An ongoing effort to provide such a software is Brightway2, which will provide integrated regionalization soon. However, this approach actually requires more data, since a resolution at country level is no longer sufficient. Spatial inventory data for water use is progressing (water database to be provided in ecoinvent 3, agricultural data for global coverage has been developed as well as power-production data at country level); however, a lot of effort is still required in this field (e.g., for industrial processes).

Danielle Tendall (Agroscope ART & ESD, ETH Zürich, Switzerland) discussed the significance of spatial resolution for the case of river water withdrawals and their impacts on aquatic biodiversity. Modeling these impacts involves the use of a species–discharge relationship (SDR), which is typically nonlinear. Previous methods do not consider the location of the withdrawal within a basin and calculate the impact with the SDR using the discharge at the mouth of the river, which is, in effect, a "best-case" estimate. In order to account for the location of the withdrawal within the basin, a higher resolution in the impact model must be used, based on ecologically defined subsections of the river, allowing aggregation of impacts from the point of withdrawal over all reaches affected downstream. Accounting for the location of withdrawal within the basin, differences in impact for a case study example in the Rhine basin reached 1 order of magnitude. This is similar to the difference between pre-existing characterization factors for basins worldwide, suggesting that the location of withdrawal within a basin is also important. However, this approach would imply knowing the location of withdrawal within a basin, and not only in which basin it occurs; and extension of this method to other regions is effort-intensive. Therefore, the paradoxical question arises of just how high spatial resolution should be (included) in impact assessment methods; but this can only be answered if the effect of the resolution increase is verified, for which the latter must be modeled in the first place.

In a short presentation, *Philippe Loubet* (Veolia Eau & Irstea, France) addressed the similar problem of spatial resolution in the WSI. Using the WSI at entire watershed scale masks the cascade effects that occur downstream of consumption in sub-basins, depending on their location. Reflecting these effects would be particularly relevant for the study of metropolitan water consumption for example, which can occur at relatively small spatial scales, maybe within only one watershed. An approach was proposed, which adapts the WSI to reflect the cascade impacts downstream of consumption in a sub-basin. For two case studies in France and Spain, this showed variation of impacts within a watershed of 1 order of magnitude. The approach is expected to be extended to further regions, and requires knowledge of water availability and consumption at a sub-basin scale.

4 Experiences from practice

This session was dedicated to the experiences, feedback, and learning from recent applications of water use LCA methods. *Markus Berger* (TU Berlin, Germany) provided an example from industry with the case of car manufacturing. The need of regionalized inventory data was addressed in a top-down way by allocating specific water consumption to the different materials used and determining the source of the materials based on import mixes and location of production sites and sectors. Results showed that 90 % of the water consumption occurs during the production phase, of which only 10 % occurs at the production site itself. The ranking of different cars according to water consumption impacts can change depending on the assumptions of location of the water consumption. However, water consumption impacts accounted for only 1–7 % of total impacts. The main challenges encountered were the uncertainties in the data and regionalization, and the trade-off between precision and applicability. Additionally, a new water footprint method was presented, which estimates basin-specific water consumption based on the balance between freshwater input, wastewater output, and evaporative water returned to the basin (via precipitation). The resulting consumption is then weighted by a use-to-availability ratio which accounts for surface and groundwater stocks, and for the vulnerability of population and ecosystems. This was calculated for global coverage, and characterization factors will be available soon.

Felix Gnehm (WWF, Switzerland) brought a perspective external to LCA, with a focus on activities and measures towards sustainable water use beyond water footprinting (WF). Experience with WF is that it is great for raising awareness, starting debates, and engaging actors. However, it has as yet been of limited use insofar as influencing policy and deriving concrete water strategies are concerned. WF can be seen as a metric with focus on a number as output, or as a method that leads to discussion and involves key stakeholders, or as a metaphor to build a narrative around a problem; but WF is not an end in itself. The next step is to take action to actually reduce water impacts in a sustainable way. Water stewardship was presented as an approach striving to reduce water footprint impacts in priority basins, while meeting the needs of agricultural development and business. Overall, it is not so essential to get the perfect methodology with perfect numbers since it is sufficient if the findings are legitimate and of concern. What really counts finally is what is undertaken in response.

Lindsay Lessard and *Samuel Vionnet* (Quantis, Switzerland) presented several case studies of water footprinting in the food and beverage sector, showing how water footprinting can currently be applied in practice. The importance of having inventory data for application of new methods was underlined, and attention was drawn to the Water Database Project, the outcomes of which will be available in ecoinvent 3. The first example concerned agricultural products (sugar cane in Brazil and maize in China).

Inventories of water use can for example be shown in form of a water balance, distinguishing inputs from surface water, groundwater, for cooling and turbined use, and outputs as returned water, consumed water, cooling water output and turbined water output. The contributions of freshwater consumption and in particular irrigation to overall damage on human health and ecosystem quality were also highlighted. A further case concerned a beverage company, which used water footprinting to identify its business units with the highest physical risk of water scarcity (where high water consumption coincided with high water stress). A last case study illustrated the use of water footprinting to support the promotion of initiatives for improved water management and corporate social responsibility in Colombia, where the inclusion of direct and indirect (supply chain) processes allowed identification of the main areas to focus on.

5 Short presentations

These presentations addressed inventory requirements and implications of impact assessment choices in the context of water footprinting. *Anne-Marie Boulay* (Ciraig, Canada) shared preliminary results on the comparison of three impact assessment methods addressing human health impacts of water consumption. The aim of the comparison was to understand the implications of modeling choices, data, and hypotheses in water scarcity indicators. The implications of regionalization choice, distinction of water sources, considerations of both consumption and withdrawal, and the data used all significantly affected results (variably according to the region). Open questions still remain to be addressed, such as which data source is most representative? What is scarcity in the case of consumption-to-withdrawal ratios? What is the most relevant spatial resolution?

Stefanie Markwardt (Institute for Energy and Environmental Research Heidelberg, Germany) contrasted inventory data requirements of several water footprint methods with the data available in an ecoprofile for the case of polyactide production. The main gaps in inventory data were found to be the quantity of water released. This would be relatively easy to measure in industrial processes. However, in agricultural cultivation it is problematic. Furthermore, the source of water used in cultivation is also uncertain, and the exact location was critical since the cultivation area was located on a border between two regions with very high (0.99) and very low (0.04) water stress index, respectively. Again, the compatibility of inventory and method was underlined as an essential point enabling application: exchange between developers of inventories and methods is necessary.

Bettina Joa (Pforzheim University, Germany) addressed the challenge of collecting inventory data for whole supply chains with a novel approach: if each supplier in the chain knows its own water intensity (cubic meter water consumed per monetary value of output), any manufacturer can estimate the water use in its supply chain by multiplying the value of the products it uses as input with the water intensity of the supplier, in a cumulative way (by matrix calculation). The same can be done with downstream processes (e.g., waste disposal). Regionalized stress factors can similarly be included in the information of each supplier. This would provide a low-effort way of systematically including water inventory data, but requires the participation of each supplier in the chain.

6 Discussion workshop

During the discussion workshop, the participants of the DF-50 analyzed four selected topics in relation to water use in LCA, the main findings of which are summarized below:

1. *What is the optimal level of regionalization*? Regionalizing the entire supply chain was considered impossible. Therefore, two levels of detail are necessary, with regionalization applied only for processes or impacts where the difference is significant. In the case of absent regionalized data, an interim approach could involve the use of archetypes, where available and meaningful. In general, a simplification of complex impact assessment methods was seen as desirable for application to complex supply chains in practice.
2. *How to address data gaps in inventories*? The minimum requirement in inventories were identified as: amount of water withdrawn, region, source (surface or groundwater), time (month), use type (consumptive, cooling, turbined, degradative), and amount of water discharged (returned). Data at a country level is not accurate enough. The separation of foreground and background processes was suggested in order to simplify background databases (achieving complete detail at all levels is not possible); however, this may lead to biases in results. Data confidentiality was seen as a large hurdle in completing inventory datasets.
3. *Can and should impacts be compared when using different methods*? It was noted that life cycle impact assessment of water use is becoming extremely complex, with an ever more complete array of methods available. This provokes either the need of weighting between methods by the developers or the challenge for practice to deal with multiple indicators for water use, which is in fact only one aspect in the whole LCA. A full LCA remains important, and should be better recognized in companies rather than focusing on individual footprints.

4. *How to deal with "positive impacts" (benefits) in LCA?* Negative impacts and benefits should not be aggregated in LCA: this could mask important problems, whereas one objective of LCA is to help identify problematic areas. However in a broader perspective, the consideration of benefits in parallel would be meaningful. LCA can already partly deal with this issue via a consequential approach, where the compensation of impacts may be taken into consideration.

7 Conclusions

Life cycle impact assessment of water consumption has developed rapidly over the past 5 years with many new methods improving the completeness of pathway coverage. Existing methods have further developed in order to improve accuracy, by addressing regionalization, temporal resolution, water source, and uncertainties in data and model assumptions (such as the choice of marginal or average effect factors). Regionalization was confirmed as essential in the case of water consumption. An optimal level has not yet been defined; however, it is clear that country level and in some cases even basin-level information is insufficient. These developments have however lead to an increase in complexity, with several consequences: some effort-consuming methods are difficult to upscale to broader spatial coverage; ensuring compatibility between impact assessment and inventory has become a challenge; applying these multiple methods in water footprinting and LCA is difficult. To handle this complexity, three main aspects must be dealt with: the development of inventories in parallel with the impact assessment method development, the implementation of regionalization in calculations, and the comparability of different impact categories related to water use. Concerning inventories, new databases and approaches to simplify data collection have been developed or are in development. Priority gaps to fill were identified as spatial information, and water release (return to the environment) data; processes affecting sensitive regions and impact categories should be addressed first. Confidentiality of data is a major hurdle to inventory data collection. Concerning the implementation of regionalization, operational software solutions are not yet available, but are upcoming. This requires an effort from both developers (such as a simplification and smoothing of characterization factor maps) and software implementers, in order to facilitate application in practice. Finally, water footprinting must remain in perspective of a full LCA; it is not an aim in itself, but should help to support action and changes in companies and policy. A humorous remark concluded the DF-50: would a future discussion forum on simplifying LCA be of use?

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